Anales del Instituto de Biología, Universidad Nacional Autónoma de México,
Serie Zoología 74(1): 67-82. 2003

Bobcat ranging behavior in relation to small mammal abundance on Colima Volcano, Mexico

ANDREW M. BURTON*
SONIA NAVARRO PÉREZ**
CUAUHTÉMOC CHÁVEZ TOVAR***

Resumen. Un lince macho adulto y una hembra adulta fueron capturados cerca de la cima del Volcán de Colima, al oeste de México. El ámbito hogareño total del macho adulto fue de 560.5 ha, el cual incluye el ámbito de la hembra, de 98.9 ha. La determinación de áreas núcleo mediante análisis de agrupamientos, ayudó a elucidar las preferencias de hábitat. El macho centró su actividad en el flujo de lava que se produjo durante la erupción de 1869 de El Volcancito, en el flanco este del Volcán de Colima. Una segunda área núcleo fue identificada como el flujo de lava de 1880 en el flanco norte del Volcán, el cual fue favorable para la hembra. La hembra también centró su actividad en el zacatonal de la vertiente oeste del volcán, entre 3100 y 3200 m. La preferencia del lince hacia los flujos de lava y el zacatonal estuvieron relacionados con su preferida forma de cazar, que consiste en el acecho de la presa y esperar, requerimientos de coberturas y posición ventajosa, así como la distribución de pequeños mamíferos en el volcán. Los pequeños mamíferos se muestrearon en los hábitats de árboles y de zacatonal en el volcán usando un diseño de trampeo replicado. La abundancia de los pequeños mamíferos fue mayor en el zacatonal, en comparación con los hábitats de árboles ($F = 34.25$; d.f. 1,16; $P < 0.0001$). La producción de semillas se esperaría que fuera mayor en el zacatonal que en el hábitat de árboles, el cual tiende a un porcentaje mayor de suelo desnudo, lo que tendría un efecto positivo en las poblaciones de pequeños mamíferos de zacatonal. La abundancia del pasto amacollado *Calamagrostis tolucensis*, así como las herbáceas, en el hábitat del zacatonal del volcán podrían proveer suficiente material vegetal para especies como *Microtus mexicanus*.

*Coordinación General de Investigación Científica, Universidad de Colima, Avenida Universidad 333, Colima 28045, Colima, México. Present address: Department of Biology, College of Science, Sultan Qaboos University, P.O. Box 36, Postal Code 123, AL-Khodh, Sultanate of Oman

**Departamento de Botánica y Zoología, Universidad de Guadalajara, Apartado postal 139, 45100 Zapopan, Jalisco, México.

***Laboratorio de Conservación de Vertebrados, Departamento de Ecología Funcional y Aplicada, Instituto de Ecología, Universidad Nacional Autónoma de México (UNAM), Apartado postal 70-275, 04510 México D.F., México

Palabras clave: *Lynx rufus escuinapae*, Volcán de Colima, oeste de México, mamíferos pequeños, perturbación, ámbito de comportamiento.

Abstract. One adult male bobcat and one adult female bobcat (*Lynx rufus*) were captured near the summit of Colima Volcano, western Mexico. The overall home range of the adult male was 560.5 ha, which encompassed the range of the adult female at 98.9 ha. Determination of core areas from cluster analysis helped elucidate habitat preferences. The adult male centered activity on a large rocky lava flow field produced during the 1869 flank eruption of the parasitic vent, El Volcancito. A second core area was identified as the 1880 lava flow on the northern flank of the volcano, which was favored by the adult female. The female bobcat also centered activity in grassland on the western slopes of the volcano between 3100 and 3200 m. Bobcat preference for the lava flows and grassland was related to their preferred mode of hunting, involving stalking prey and lying in wait, requiring cover and vantage points, and the distribution of small mammals on the volcano. Small mammals were sampled within tree and grassland habitats on the volcano using a replicated trapping design. Abundance of small mammals was greater in grassland as opposed to wooded habitats. Seed production can be expected to be greater in grassland habitats favoring high densities of small mammals. The high abundance of the bunchgrass *Calamagrostis tolucensis*, along with herbs, in grassland habitats on the volcano should provide sufficient vegetative material for species such as *Microtus mexicanus*.

Key words: *Lynx rufus escuinapae*, Colima Volcano, western Mexico, small mammals, disturbance, ranging behavior.

Introduction

Although habitat use, habitat requirements, and general ecology of the bobcat (*Lynx rufus*) have been extensively studied in the continental United States (Nowell & Jackson 1996, Kitchener 1991), current research on the bobcat in Mexico is limited to the work of Romero (1993), who published an account of bobcat diet on an extinct volcano in Central Mexico, and Delibes *et al.* (1997), who studied seasonal food habits of bobcats in Southern Baja California.

Following their fieldwork on the diet of bobcats in Southern Baja California, Delibes *et al.* (1997) suggested that more research in the south of the bobcats range, in Mexico, would be very useful for a more comprehensive understanding of the species ecology. Nowell & Jackson (1996) were more specific and identified the need for further research on the distribution and status of the bobcat in the Western Mexican Sierras, due to deforestation and degradation of the dry scrub, oak, and pine habitats.

Habitat use of predators is often related to prey abundance and, even to a greater extent, vulnerability (Nowell & Jackson 1996, Guggisberg 1975). Field studies on the bobcat *Lynx rufus* have shown that this predator prefers broken habitats, often with rocky ledges. Prey abundance, protection from severe weather, availability of rest shelters, cover, and freedom from human disturbances are considered the most important factors in habitat selection (McCord 1974). Bobcats often prefer grassy and brushy habitats where lagomorph and rodent abundance may be higher (Rolley & Wade 1985). Whereas Heller & Fendley (1982) found bobcats to prefer bottomland hardwood as their primary habitat, this was related to bottomland hardwoods providing suitable cover for rest shelters, escape cover, and protection from weather. Old field habitats with high availability of small mammals were shown to be a favored habitat for bobcats (Fendley & Buie 1982).

In this study we attempt to explain bobcat ranging behavior in relation to prey abundance and habitat characteristics on Colima Volcano, western Mexico.

Study area

Fieldwork was undertaken from January 1994 to May 1997 on the 3850 m Colima Volcano (19°31’ N, 103°37’ W), at altitudes between 2800 and 3400 m.

The climate of the study area includes a distinct short summer wet season (June-October) and a prolonged dry season (November-May). During the rainy season, rainfall results from low-pressure systems with resulting thunderstorms, larger and more intense tropical storms, and hurricanes. Annual rainfall averages 800-1000 mm (Biondi *et al.* 1999). The dry season begins with the invasion of cold dry high pressure cells from the north, occasionally accompanied by cold fronts producing snow falls at high altitudes (above 3000 m). Minimum and maximum temperatures for the period 1994-1997 are -4°C and 17°C (Galindo *et al.* 1998).

Vegetation is composed of a mosaic of pines, shrubs, grasses and herbs that date from the 1913 explosive eruption of the Volcano, which destroyed all vegetation on the slopes of it (Saucedo-Girón 1997). Continuing disturbance on the western slopes of the volcano due to fires and recent volcanic activity has maintained a plant community in succession.

The most recent volcanic activity began with extensive lava flows on the southern flank of the volcano beginning in late November 1998 (Smithsonian Institution 1998). Later, this effusive activity changed to more explosive release of ash, accompanied with the ejection of incandescent blocks, and occasionally, pyroclastic flows (Smithsonian Institution 1999). Current activity is continuing effusion of a viscous lava dome at the summit and lava flows down the southern flanks of the volcano (Smithsonian Institution 2002). Access to the general public is currently restricted to within 6.5 km of the active vent (Smithsonian Institution 2002).

Methods

Bobcats

Bobcats were captured in BMI No. 2, double-coil spring, soft-catch leg-holds, set as hole sets and trail sets and baited with bobcat urine and fresh fish. In addition, a piece of tin or a small bunch of feathers was hung over the trap site by a piece of string to lure in cats by using their natural curiosity. We ran a trap line of up to 28 traps at any one time. Captured bobcats were immobilized with 5-10 mg/kg zoletil (tiletamine hydrochloride/zolazepam hydrochloride mixture: Virbac Laboratories) and fitted with a radio-collar with mortality sensor (Telonics, Inc., Mesa, Arizona).

Radio-collared bobcats were tracked using a flexible H antenna and portable receiver by 4WD vehicle, on foot, and by fixed-wing aircraft. Radio-collared cats were monitored throughout the year. The design of the sampling scheme for radio-tracking followed the work of Kenward (1987), Pollock (1987) and Burton & Olsen (2000), except that fewer fixes were taken per day, the time interval between fixes was greater and the sampling period covered a full annual cycle. Nighttime radio tracking was also undertaken to ensure that foraging areas were obtained and not just daytime den sites.

Outer convex polygons (OCP) (Kenward 1987, 1990) were used to determine overall home range since this facilitates comparison with other studies. However, the problem with the OCP is that range size is influenced strongly by peripheral fixes, consequently the range area can include areas or habitats that are never visited, and there is no indication of how intensively different areas of the range are used (Harris *et al.* 1990). Incremental cluster analysis (Kenward 1987, 1990) was used to identify core areas within the overall home range. Analyses were performed using the computer program Ranges V (Kenward & Hodder 1996). The percentage of fixes that constituted core areas was identified from utilization distributions, which used cluster analysis (Kenward 1990).

Small mammals

In order to compare the abundance and biomass of small mammals between grassland and woodland habitats (excluding lava flows), a replicated trapping design was used with three replicates within each of two habitat types. A six by five trapping grid was utilized making a total of 30 traps in each replicate with an inter-trap distance of 10 m. We used Sherman live traps baited with a mixture of rolled oats, lard, and vanilla essence. Trapping was undertaken for two nights on three separate occasions during the 1994 dry season; once in January, then in late March, and finally in May for a total of 1,080 trap nights. For each rodent captured, we identified the species, sex, reproductive condition, age, weight, and ear size. Each rodent was also toe clipped following the method of Ceballos (1989) for future identification. For calculating rodent density, 10 m out from the edge of the trapping grid was added to account for the movement of rodents from outside of the grid (Fa *et al.* 1990) so that total trapping area for a 60 x 50 m trapping grid was considered as 4200 m^2 or 0.42 ha.

Differences in the abundance of small mammals between grassland and woodland were tested for significance by 1-way analysis of variance with the statistical package Statistix (Analytical Software 1990).

Vegetation

Vegetation diversity and structure were determined for small mammal quadrants and for bobcat range areas. Thirty-seven quadrants were selected at random between 2800 to 3100 m on the slopes of the volcano and within El Playón. Of these 37 quadrants, 19 were in grassland and 18 in tree communities (10 quadrants in communities dominated by *Pinus hartwegii*, 4 in *Abies religiosa*, and 4 in *Alnus firmifolia*). Grassland communities were divided into two types: grassland subjected to continued disturbance (successional grassland), and established grassland communities dominated by the bunchgrass *Calamagrostis tolucensis* within El Playón.

Vegetation description followed the Zurich-Montpellier methodological approach (Westhoff & Maarel 1978), which was modified by Cleef (1981). A quadrant of 25 m x 25 m (625 m^2) was sampled in order to determine tree, shrub, and herbaceous layers, within which a smaller 5 x 5 m (25 m^2) quadrant was sampled in order to characterize grass species. Vascular plant species data collected for each site were: *1)* complete floristic inventory; *2)* percentage cover and modal height of each plant species within each layer (layers were defined by vegetation height: 5 to 150 cm = herbs, 150 -300 cm = shrubs, and >300 = trees); 3) percentage of bare soil, rocks, and leaf litter and; *4)* assessment of volcanic or anthropogenic disturbance by quantifying impacts from volcanic activity (fires, ash fall, and pyroclastic flows) and human activities (logging, grazing, recreational activities). Three indices of species diversity were calculated: Species richness (S), Diversity (H), and Evenness (E). Species diversity was calculated as the total number of species present; Diversity was calculated from the equation –sum (Pi (ln Pi)) (Shannon Diversity Index) where Pi is the importance probability in element i; and evenness was calculated from the equation H/ln S. Plants were identified in the field, but representative samples were collected for taxonomic analysis and are deposited in a reference collection at the Herbarium of the Instituto de Botánica, Universidad de Guadalajara.

Habitat description. Habitat variables that were measured at quadrants were altitude, aspect, humidity, exposure, geomorphology, temperature, soil type, organic material, and volcanic or human disturbance. Bare soil, rocks, and ground layer vegetation, were calculated as a percentage of total ground area.

Variable analysis. Floristic composition, species diversity, and dominance by quadrant were estimated by absolute and relative frequency. Multivariate analysis of ecological data using Pcord4 software (McCune & Mefford 1995) was used to classify vegetation by using the Bray-Curtis ordination technique[1] deploying the following two strategies: *1)* intrinsic analysis (main matrix) of quantitative data where importance values were calculated as the average of relative density, relative frequency, and cover (rare species occurring alone, and outliers, were excluded from the analysis (Curtis 1959); *2)* extrinsic analysis (secondary matrix) of quantitative and qualitative data from habitat variables was calculated. The matrices were ordinated by sociological analysis using Bray-Curtis variance-regression (Beals 1965, 1973, 1984 *cited in* Vázquez-G. & Givnish 1998).

Results

Bobcats

Sample size is small because: *1)* the study area was small (10 km^2 <) due to the logistic difficulties of working on a 4000 m high active volcano; *2)* the subspecies *L. rufus escuinapae* which occurs on Colima Volcano is considered endangered (Sunquist 1991) and is rarely encountered; *3)* particular individuals were difficult to capture; and *4)* after considerable effort, a second male that was captured, was killed by a Puma *Puma concolor* before sufficient position fixes could be obtained. In total, radio telemetry data were obtained for one adult male and one adult female. Forty independent locations were obtained for the adult male and 52 independent locations for the adult female.

Home range size and activity. The home range (OCP) of the adult male was 560.5 ha and his range totally encompassed the female's range of 98.9 ha. Determination of core areas from cluster analysis showed that the male centered activity on a rocky lava flow field, which dates from the 1869 eruptions of a parasite vent known as El Volcancito (De la Cruz Reyna 1993) on the eastern flank of the volcano (Fig. 1). A second, smaller core area was indicated on an earlier XIX century lava flow dated at around 1880 (hereafter referred to as the 1880 lava flow, Smithsonian Institution 1999), within the range of the adult female. Activity of the adult female was almost exclusively concentrated on this lava flow, with additional core areas on the 1869 rocky lava flow field at the base of the parasitic vent, and on the western slopes of the volcano between 3100 and 3200 m (Fig. 1). Core areas totaled 99.0 ha for the male and 26.6 ha for the female.

[1] Bray-Curtis ordination is a family of techniques that share: *1)* the calculation of a distance matrix using an appropriate distance to assess compositional dissimilarity between each pair of samples; *2)* selection of real or synthetic reference samples, which will determine the orientation of axes and; *3)* the projection of samples onto each axis by their distance to previous determined reference samples (Bray & Curtis 1957).

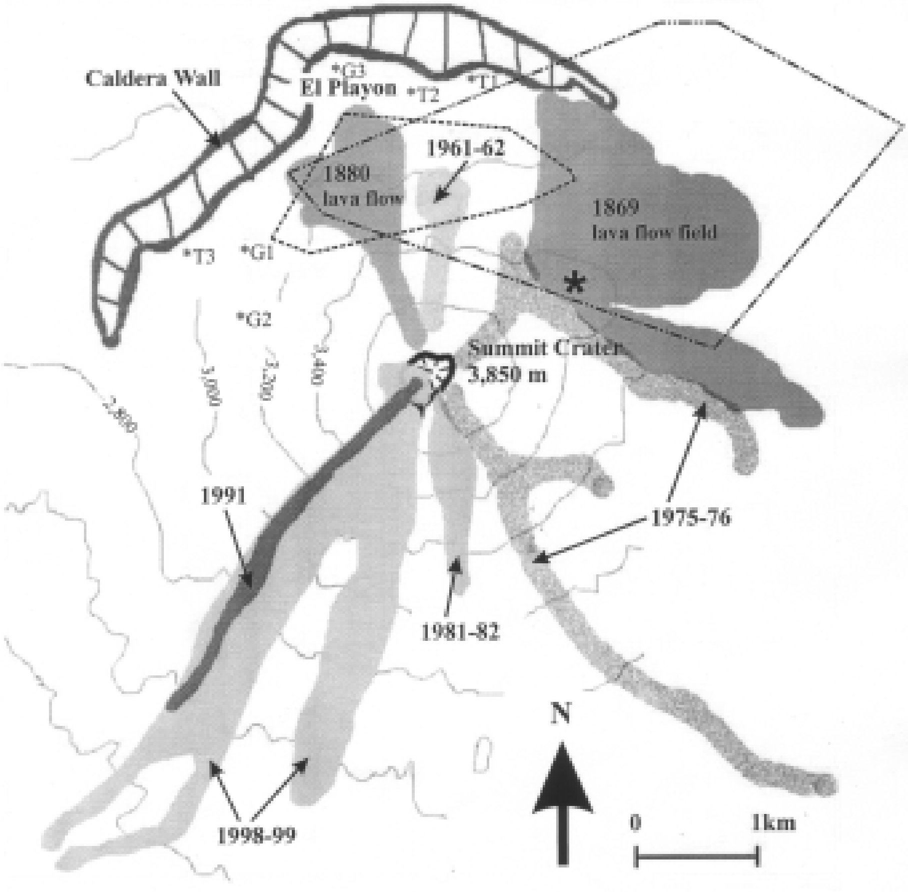

Fig. 1. Outer convex polygons for bobcat ranges (female = dashed line, male = dashed and dotted line) near the summit of Colima Volcano, western Mexico. Individual lava flows are indicated and the location of small mammal quadrants are shown (T = trees, G = grassland). The large asterisk to the top right of the summit crater marks the eruptive vent of the parasitic cone El Volcancito (3 500 m), responsible for the 1869 lava flow field. Figure modified from Smithsonian Institution (1999).

Small mammals

Abundance of small mammals was greater in grassland habitat as opposed to wooded (pines/fir) habitat ($F = 34.25$; d.f. 1,16; $P < 0.0001$), and overall abundance showed an increase toward the end of the dry season (January, grassland 24 ind./ha vs. woodland 3 ind./ha; March, grassland 29 ind./ha vs. woodland 9 ind./ha; May, grassland 38 ind./ha vs. woodland10 ind./ha). Two species of small mammals were captured in wooded habitats; the black-eared mouse *Peromyscus melanotis* and the Mexican vole *Microtus mexicanus*. Captures of both species were similar until the end of the dry season when there was a dramatic increase in the numbers of *P. melanotis* as opposed to *M. mexicanus* (69% vs. 31% of captures). In grassland habitats, five species were captured; *P. melanotis*, *M. mexicanus*, the western harvest mouse *Reithrodontomys megalotis*, the Mexican wood rat *Neotoma mexicana*, and Goldman's small-eared shrew *Cryptotis goldmani*. Percent captures and biomass were calculated for *P. melanotis* and *M. mexicanus* but not for the other three species due to low capture rate (*R.. megalotis* = 4; *N. mexicana* = 1; *C. goldmani* = 1). *M. mexicanus* exhibited a decline from 34% of captures in January to 19% of captures in May, whereas *P. melanotis* showed an increase from 60% of captures in January to 73% of captures in May, with a peak of 76% of captures in March. In terms of biomass available for foraging bobcats in woodland habitat *P. melanotis* increased from a mean of 33g/ha in January to 83g/ha in March with a peak of 150 g/ha in May, and *M. mexicanus* increased from a mean of 51g/ha in January to a peak of 127 g/ha in March before declining to 101 g/ha in May. In grassland *P. melanotis* increased from 300g/ha in January to 467g/ha in March and peaked in May at 583g/ha. *M. mexicanus* showed a reduction from 254 g/ha in January to 229 g/ha in March before reaching a peak of 686 g/ha in May. Comparing total biomass of rodents between the two habitats, the significance of grassland as a habitat rich in available calories to foraging bobcats as opposed to woodland ($F = 50.83$; d.f. 1,16; $P < 0.0001$) becomes apparent (rodent biomass for January, grassland 554g/ha vs. woodland 84g/ha; March, grassland 696g/ha vs. woodland 210g/ha; May, grassland 1,269g/ha vs. woodland 251g/ha).

A further analysis was undertaken to compare the two sample sites within the disturbed successional grassland on the western face of the volcano with the grassland or bunchgrass habitat within El Playón. Although in this case, sampling is unequal (the two grassland sites on the western face of the volcano were combined and means calculated for the three different sampling periods in order to compare against the one grassland site within El Playón), the analysis does suggest a difference in numbers of small mammals between the two areas, with more small mammals captured in the successional grassland habitat on the western face of the volcano ($F = 9.03$; d.f. 1,4; $P < 0.05$). This difference is discussed under vegetation analysis.

Vegetation

Coefficient of variation (CV) for quadrants sampled in alpine grassland and tree communities were different (alpine grassland 72.50 and tree communities 29.28). However, species compositions in alpine grassland and tree communities were regular and similar. The total species composition for the whole study area was 108 species of 67 genera that belong to 37 families. Of these, grassland contained 73 species, while tree communities had 80 species.

Plant families that contributed to overall species richness in the total sampled area were Asteraceae with 24 species and 10 genera, and Poaceae with 16 species and 9 genera. Other diverse families were Caryopyllaceae and Apiaceae, each with 5 species and 3 genera; Ericaceae and Lamiaceae with 4 species and 3 genera, Rosaceae with 3 genera and 3 species; Pinaceae and Solanaceae with 2 genera and 3 species; and Adiantaceae, Leguminosae, and Salicaceae with 1 genera and 3 species.

Alpine grassland, structure and dominance. The predominant vegetation type was the bunch grass *Calamagrostis tolucensis*. Species with a high frequency of occurrence in the alpine grassland quadrants were the grass species *Calamagrostis tolucensis* (25%), *Pinus hartwegii* (17%), the typical high altitude plants *Arenaria oresbia* and *Draba jorullensis* (12%), the grasses *Aegopogon centroides* and *Festuca tolucensis*, and the shrubs *Coreopsis petrophiloides* and *Lupinus montanus* all present in 10%. The grasses *Agrostis tolucensis*, *Muhlenbergia virenens* and *Muhlenbergia macroura*, as well as the shrubs *Senecio angulifolium*, *Stevia lucida* and *Budleja cordata*, the herb *Alchemila procumbens*, and the fern *Adiantum andicola* were in 8%. *Abies religiosa* had a lower frequency of occurrence at 5%. Other species were less than 5%.

For grassland, average species richness was 2.4 while the total average quadrant was 10.5; Shannon diversity for total average quadrants was 2.052 and evenness 0.954.

From classification analysis (using unweighted pairgroup average)[2] of grassland communities, two communities are recognised: 1) one is a homogeneous open community nearly always found on the slopes of the volcano, typically on older lava flows and talus slopes. This is principally composed of bunch grass *Calamagrostis tolucensis* and shrubs. Trees were few or absent and ground cover was made up of grasses, herbs, and ferns. Bare ground was also present and sample quadrants were characterized as having many rocks greater than 1 m in diameter; 2) the second community was a grassland community poor in species diversity and considered unstable by the classification analysis. This community was considered invasive and most often found on flat open ground that has either been subjected to flash flooding or fire. At one site this community was established at the location of an old sawmill. Bare soil was an important percentage of ground cover of these communities and trees were considered relicts of previous communities.

[2] Unweighted Pair Group Average is a hierarchical polythetic agglomerative technique that groups classes into a hierarchy, using information from all samples. Each sample is assigned a cluster in a hierarchy of increasingly more inclusive clusters until one cluster contains all the samples.

Tree community, structure and dominance. Dominant tree species were *Abies religiosa* 63%, *Pinus hartwegii* 56% and *Alnus firmifolia* 42%. Percent occurrence for shrubs were *Senecio angulifolium* 40%, *Ribes ciliatum* and *Senecio callosus* 20%, *Eupatorium pichichensis* 10.5%, *Loeslia mexicana* 12.5%, and the leguminous shrub *Lupinus reflexus* 18.5%; ferns *Polypodium madrense* and *Asplenium monanthes* at 21.5 % and 15% respectively; grasses *Calamagrostis tolucensis* 17%, *Festuca tolucensis* 11%, *Poa annua* 10%, *Muhlenbergia quadridentata* 19%; and the herb *Cestrum confertiflorum* 18%. Other species occupied less than 10% of the quadrants.

Richness (S), diversity (H), and evenness (E), among tree communities were homogenous and similar: *Abies religiosa* S = 33; H = 3.161; E = 0.904; *Alnus firmifolia* S = 37; H = 3.258; E = 0.902 and *Pinus hartwegii* S = 41; H = 3.304 and E = 0.890. The *Pinus hartwegii* community was the most diverse and rich, but also was the less even.

Average species richness for tree communities was 2.8 while total average quadrant richness was 12.5; the average Shannon diversity for all quadrants was 0.686 and the total diversity average of evenness 0.3653.

Sociological ordination

Grassland

Intrinsic analysis. In the Bray-Curtis ordination[3] we considered 19 sites and 51 species with the relationship among samples being based on major groupings. Ordination occurred on three axes from which the percentage of variance that occurred in a community was related to factors that affect that community.

Extrinsic analysis. Relationship to environmental data was superimposed on each ordination and correlation with ordination axes was determined by regression. The results in this analysis indicated that bare soil and quadrant explain differences in site composition and variance in species abundance between sites. For grassland a cumulative 55.14 % of the variance was extracted by three axes from the original distance matrix: first axis 24.95; second axis 14.94 and; third axis 15.25. The ordination resulted in a "T" arrangement. Axis 1 showed a significant correlation with bare soil ($n = 19$; $r = 0.589$; d.f. 17; $P < 0.005$) and quadrant ($n = 19$; $r = 0.476$; d.f. 17; $P < 0.005$). A significant relationship was found between the richness of grassland and altitude ($n = 19$; $r = 0.492$; d.f. 15; $P < 0.005$), and organic matter ($n = 17$; $r = 0.538$; d.f. 12; $P < 0.005$).

Overall the tendency is for diversity values to be the same despite the separation of the two grassland communities in the analysis. Species richness and species dominance is similar, however, abundance is less for the second community due to an increase in the percentage of bare ground.

[3] Technique used for the ordination of sampled sites in three-dimensional space based on the similarities and composition of species sampled.

Tree communities

Intrinsic analysis. In the Bray-Curtis ordination we considered 18 sites and 80 species with the relationship among samples being based on major groupings. Ordination occurred on three axes from which the percentage of variance that occurred in a community was related to factors that affect that community.

Extrinsic analysis. Relationship to environmental data was superimposed on each ordination and correlation with ordination axes was determined by regression. The results in this analysis also indicated that bare soil and quadrant explain differences in site composition and variance in species abundance. For tree communities a cumulative 547.96 % of the variance was extracted by three axes from the original distance matrix: first axis 20.73; second axis 16.99 and; third axis 10.24. The ordination resulted in a "T" arrangement. Axis 1 showed two significant negative correlation with slope ($n = 18$; $r = 0.683$; d.f 12; $P < 0.001$) and with organic matter ($n = 18$; $r = 0.490$; d.f 15; $P < 0.005$).

Discussion

The preference of bobcats to use the old lava flows is in line with observations by Bailey (1974), where he considers the numerous lava flows, volcanic craters, and caves of the Snake River Plain in southeastern Idaho to be ideal bobcat habitat. Heller & Fendley (1982) consider that bobcat habitat must provide suitable cover for rest shelters, escape cover, and protection from weather. We believe that the older rocky lava flows with their numerous crevasses and small caves provide excellent suitable habitat for bobcats on Colima Volcano, and this preference also probably relates to their preferred method of hunting, which involves stalking prey and lying in wait (Marston 1942, Guggisberg 1975). In addition, bobcats are well known for their preference for ledges where they can detect prey more readily and pounce upon it (McCord 1974, D. Wroe pers. comm.). Small mammal abundance was not determined quantitatively for the lava flows, however, the evidence of numerous runs and burrows did indicate that small mammals were more abundant on the old lava flows than the wooded sites sampled within El Playón. In many areas the substrate was more conducive to the development of burrows and the many crevasses within the lava flow presumably provide ample shelter. In addition, at the head of the two flows, especially the 1880 flow at an altitude of 3300 to 3400 m, floristic diversity and structure was similar to that recorded for grassland on the western face of the volcano, and runs and burrows of the rodents were not only particularly numerous, but individual rodents were often sighted scurrying towards burrows.

The vegetation found at the head of the 1880 lava flow; the base of El Volcancito; grassland between the 1880 and 1869 lava flows (excluding the 1960-1961 lava flow which is devoid of vegetation); and on the western face of the volcano at altitudes between 3000 to 3200 m, can best be described as a high altitude continuously disturbed successional vegetation. This is because at comparative altitudes on the neighboring extinct Nevado de Colima volcano, there occurs a forest of *Pinus hartwegii* where individual trees have been dated to be 400 years b.p. (Biondi *et al.* 1999). In addition, the tree line on Nevado de Colima extends up to an altitude of 4,000 meters (Biondi 2001).

Colima Volcano is one of the most active volcanoes in North America (De la Cruz Reyna 1993). A particularly violent Plinian eruption in 1913 (Saucedo-Girón 1997) destroyed all vegetation on the slopes of the volcano and within El Playón. Subsequent eruptions during the last century (De la Cruz Reyna 1993) and including the current eruptive episode (Smithsonian Institution 1998, 1999, 2000, 2001, 2002) have maintained a community of successional vegetation under constant change dominated by grasses and *Lupinus excelsus*.

This appears to favor a high density of small mammals, and coupled with the numerous shelter and suitable den sites on the lava flows, provides for excellent bobcat habitat. Indeed, bobcats are known to prefer open areas of early successional vegetation for hunting (Heller & Fendley 1982). In addition, Rolley & Warde (1985) found bobcats in southeastern Oklahoma to prefer brush and grass fields. They quote the work of Hamilton (1982) on the Ozark Plateau in southern Missouri where bobcats were found to prefer brushy fields, grassy openings, and oak and pine regeneration areas. From snow tracking it was observed that most attempts to capture cottontails (*Sylvilagus floridanus*) and small mammals occurred in brushy fields and bottomland hardwoods, whereas mature stands of pine, oak, and mixed oak-pine forests were avoided.

That bobcats were not located within the wooded flat areas of El Playón can be related to the observed low abundance of small mammals and high percentage of bare ground, with a lack of suitable shelter and den sites. It may also be related to the movements of resident pumas, who were found to use this area as a corridor between the western and eastern slopes of the Colima volcanic complex (unpublished radio-tracking data from three adult male pumas). The male bobcat that was killed by a puma was found along this route at the front of the 1869 lava flow.

Reported bobcat densities range from 1-38 resident adults per 25 km^2 (Nowell & Jackson 1996). This indicates a variation in home range size for bobcats of 66 to 2,500 ha. Nowell & Jackson (1996) suggest that high environmental productivity in the southeastern U.S. and California coastal regions is responsible for the dense populations of bobcats found in these areas. The home range of the female bobcat at 98.9 ha and the location of her core areas indicate a relatively high abundance and diversity of rodents on the slopes of Colima Volcano. Small mammals have been found to be an important component of the diet of bobcats in Mexico (Delibes & Hiraldo 1987, Delibes *et al.* 1997), although Romero R. (1993) found the endemic volcano rabbit *(Romerolagus diazi*) to be the principal prey of bobcats on the extinct Pelado Volcano in Central Mexico. On Colima Volcano, in addition to the high densities of small mammals, the two cottontail rabbits *Sylvilagus floridanus* and *Silvilagus cunicularius* were reported during this study and were found to be relatively abundant, but patchy in distribution. The most consistent sign of rabbits (fecal pellets and digging) were most frequently observed on the western face of the volcano (S. Navarro), further lending support to the importance of the grass and *Lupinus excelsus* successional vegetation on the western slopes of the volcano, and elsewhere, as an important habitat for bobcat prey. However, the importance of small mammals in the diet of bobcats is sometimes overlooked in favor of ungulates and lagomorphs. Koehler & Hornocker (1989) found voles (*Microtus* spp.) to be the most frequent item in bobcat scats from the population they studied in Idaho, with voles occurring in 65 and 40% of scats in winter and summer, respectively. Future research should concentrate on scat analysis to test the importance of small mammals in the diet of bobcats inhabiting Colima Volcano.

The greater range of the adult male bobcat (560.5 hectares) is related to the polygynous mating behavior of bobcats (Fendley & Buie 1982). This can best be described as a trade-off between obtaining access to as many females as possible and the need to defend such females against cuckoldry from neighbors and transients. That the size of the home range of our male bobcat was at the lower end of that recorded for bobcats elsewhere (Fendley & Buie 1982, Nowell & Jackson 1996) suggests an adequate food supply and therefore, reduced home range size of females.

Volcanoes are best known for their destructive effects (Simkin & Siebert 1994), however, they produce new habitat for many species of plants and animals, whether by altitudinal variation or by maintaining successional communities due to disturbance from volcanic activity. This study has shown the beneficial aspects of frequent volcanic activity at Colima Volcano. However, the negative effects from a reoccurrence of a devastating 1913 type eruption, predicted for this century (Martin Del Pozzo *et al.* 1995) is not known, since few data were collected at the time of the 1913 eruption. Detailed studies following such an event, such as those obtained for Mount St. Helens, Washington (Franklin *et al.* 1985, Adams *et al.* 1987, Hemstrom & Emmingham 1987), would be of great interest.

Acknowledgments. We especially thank Melchor Ursúa Quiroz, Director of Civil Defense and Chief of the Colima Fire Department for logistical support during the study, including the loan of 4WD vehicles. Radio-collars and field expenses for studying the bobcats were provided by research grant B062 from the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), México, and from funds provided by Alfonso Franco, President of the Organización para la Conservación, Estudio y Análisis de la Naturaleza (OCEAN), A.C., México. Tim Fendley showed the first author how to successfully trap bobcats by hole sets and trail sets, and Duggins Wroe captured the second male, which was later killed by a puma. Aerial radio-telemetry was made possible due to the support of Capt. Ernesto Gómez Hoffman and his 2-seater experimental acrobatic aircraft “Yacana”. Gerardo Ceballos, Head of the Laboratory for Vertebrate Conservation, Institute of Ecology, Universidad Nacional Autónoma de México (UNAM), suggested fieldwork on the small mammal community of Colima Volcano, and is especially thanked for procuring a post-doctoral position that was awarded to the first author by the Institute of Ecology, UNAM.

Literature cited

ADAMS, A.B., E.P. SMITH & A.R. KRUCKEBERG. 1987. Plant survival, growth form and regeneration following the 18 May 1980 eruption of Mount St. Helens, Washington. *Northwest Science* 61: 160-170.

ANALYTICAL SOFTWARE. 1990. *Statistix 3.1. An interactive statistical analysis program for microcomputers*. St. Paul, Minnesota, Analytical Software.

BAILEY, T.N. 1974. Social organization in a bobcat population. *Journal of Wildlife Management. 38:* 435-466.

BIONDI, F., I. GALINDO ESTRADA, A. BURTON, S.E. METCALFE, D.R. CAYAN & W.H. BERGER. 1999. A 400 year tree ring chronology from the North American tropics. P. 161-162. *In:* T.R. Karl (ed.) *Proceedings of the 10th Symposium on Global Change Studies*. American Meteorological Society, Boston, Massachusetts.

BIONDI, F. 2001. A 400-year tree-ring chronology from the tropical treeline of North America. *Ambio 30:* 162-166.

BRAY, J.R. & J.T. CURTIS. 1957. An ordination of upland forest communities of southern Wisconsin. *Ecological Monographs 27:* 325- 349.

BURTON, A.M. & P. OLSEN. 2000. Niche partitioning by two sympatric goshawks in the Australian wet tropics: Ranging behaviour. *Emu 100:* 216-226.

CEBALLOS, G. 1989. *Population and community ecology of small mammals in a tropical deciduous forest in western Mexico*. Ph.D. dissertation. University of Arizona, Tucson.

Cleef, A.M. 1981. *The vegetation of the páramos of the Colombian cordillera oriental*. Cramer, Vaduz.

CURTIS, J.T. 1959. *The vegetation of Wisconsin. An ordination of plant communities.* University of Wisconsin Press, Madison, Wisconsin.

DE LA CRUZ REYNA, S. 1993. Random patterns of occurrence of explosive eruptions at Colima Volcano, Mexico. *Journal of Vulcanology and Geothermal Research 55:* 51-68.

DELIBES, M. & F. HIRALDO. 1987. Food habits of the bobcat in two habitats of the southern Chihuahuan desert. *Southwestern Naturalist 32:* 457-461.

DELIBES, M., M.C. BLÁZQUEZ, R. RODRÍGUEZ & S.C. ZAPATA. 1997. Seasonal food habits of bobcats (*Lynx rufus*) in subtropical Baja California Sur, Mexico. *Canadian Journal of Zoology 74:* 478-483.

FA. J.E., J. LÓPEZ-PANIAGUA, F.J. ROMERO, J.L. GÓMEZ & J.C. LÓPEZ. 1990. Influence of habitat characteristics on small mammals in a Mexican high-altitude grassland. *Journal of Zoology 221:* 275-292.

FENDLEY, T.T. & D.E. BUIE. 1982. Seasonal home range and movement patterns of the bobcat on the savannah river plant. P. 237-259. *In:* S.D. Miller & D. Everet (eds.) *Cats of the world: Biology, Conservation and Mangement. 2nd International. Cat Symposium.* Ceaser Kleberg Wildlife Research Institute and National Wildlife Federation, Kingsville, Texas.

FRANKLIN, J.F., J.A. MACMAHON, F.J. SWANSON & J.R. SEDELL. 1985. Ecosystem responses to the eruption of Mount St. Helens. *National Geographic Research, Spring 1985:* 198-216.

GALINDO, I., A. ELIZALDE, R. SOLANO & M. CRUZ. 1998. *Climatología del Volcán de Fuego de Colima*. Universidad de Colima, Colima, México.

GUGGISBERG, C.A.W. 1975. *Wild cats of the world.* Taplinger, New York.

HAMILTON, D.A. 1982. *Ecology of the bobcat in Missouri*. M.S. Thesis, University of Missouri, Columbia, Missouri.

HARRIS, J., W.J. CRESSWELL, P.G. FORDE, W.J. TREWHELLA, T. WOOLLARD & S.WRAY. 1990. Home range analysis using radio-tracking data – a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review 20:* 97-123.

HELLER, S.P. & T.T. FENDLEY. 1982. Bobcat habitat on the Savannah River Plant, South Carolina. P. 415-423. *In:* S.D. Miller & D. Everet (eds.) *Cats of the world: biology, conservation and mangement. Second International Cat Symposium.* Ceaser Kleberg Wildlife Research Institute and National Wildlife Federation, Kingsville, Texas.

HEMSTROM, M.A. & W.H. EMMINGHAM. 1987. Vegetation changes induced by Mount St. Helens eruptions on previously established forest plots. *In:* D.E. Bilderback (ed.) *Mount St. Helens 1980: Botanical consequences of the explosive eruptions.* University of California Press, Berkeley, pp. 188-209.

KENWARD, R. 1987. *Wildlife radio tagging: equipment, field techniques and data analysis* (Biological Techniques Series), Academic, London.

KENWARD, R. 1990. *Ranges IV: Software for analysing animal location data.* Institute of Terrestrial Ecology, Wareham, UK.

KENWARD, R.E. & K.H. HODDER. 1996. *Ranges V: An analysis system for biological location data.* Institute of Terrestrial Ecology, Wareham, UK.

KITCHENER, A. 1991. *The natural history of wild cats.* Christopher Helm, London.

KOEHLER, G.M. & M.G. HORNOCKER. 1989. Influences of seasons on bobcats in Idaho. *Journal of Wildlife Management 53*: 197-202.

MARSTON, M. A. 1942. Winter relations of bobcats to white-tailed deer in Maine. *Journal of Wildlife Management. 6:* 328-337.

MARTIN DEL POZZO, A.L., M. SHERIDAN, D. BARRERA, J.L. HUBP & L. VÁZQUEZ SELEM. 1995. Potential hazards from Colima volcano, Mexico. *Geofísica Internacional 34:* 363-376.

MCCORD, C.M. 1974. Selection of winter habitat by bobcats (*Lynx rufus*) on the Quabbin Reservation, Massachusetts. *Journal of Wildlife Management 55:* 428-437.

MCCUNE, B. & M.J. MEFFORD. 1995. *PCORD Multivariate analysis of ecological data, version 4.19.* MjM Sofware Design, Gleneden Beach, Oregon.

NOWELL, K. & P. JACKSON. 1996. Wild cats: Status survey and conservation action plan. IUCN, Gland.

POLLOCK, K. 1987. Experimental design of telemetry projects. *Journal of Raptor Research 21*: 129-131.

ROLLEY, R.E. & W.D. WARDE. 1985. Bobcat habitat use in southeastern Oklahoma. *Journal of Wildlife Management 49:* 913-920.

ROMERO R., F. 1993. Análisis de la alimentación del lince (*Lynx rufus escuinapae*) en el centro de México. *In:* R. A. Medellín & G. Ceballos (eds.) *Avances en el estudio de mamíferos de México,* Publicaciones Especiales, Vol. 1. Asociación Mexicana de Mastozoología, A.C., México, D. F., pp. 217-230

SAUCEDO-GIRÓN, R. 1997. *Reconstrucción de la última erupción explosiva del Volcán de Colima en 1913.* Tesis de Maestría, Instituto de Geofísica, Universidad Nacional Autónoma de México, México, D.F.

SIMKIN, T. & L. SIEBERT. 1994. *Volcanoes of the world. A regional directory, gazetteer, and chronology of volcanism during the last 10,000 years.* Smithsonian Institution, Global Volcanism Program, Geoscience Press, Tucson, Arizona.

SMITHSONIAN INSTITUTION. 1998. Colima. *Bulletin of the Global Volcanism Network 23:* 10.

SMITHSONIAN INSTITUTION. 1999. Colima. *Bulletin of the Global Volcanism Network 24:* 01.

SMITHSONIAN INSTITUTION. 2000. Colima. *Bulletin of the Global Volcanism Network 25:* 06.

SMITHSONIAN INSTITUTION. 2002. Colima. *Bulletin of the Global Volcanism Network 27:* 05.

SUNQUIST, F.C. 1991. The living cats. *In:* J. Seidensticker & S. Lumpkin (eds.) *Great cats, majestic creatures of the wild*. Rodale, Pennsylvania, pp. 28-53.

VÁZQUEZ-G., J.A. & T. J. GIVNISH. 1998. Vegetation of Cerro Grande Massif, Sierra de Manantlán, México: ordination of a long altitudinal gradient with high species turnover. *Boletín del Instituto de Botánica, Universidad de Guadalajara 6:* 227-250.

WESTHOF, V. & E. VAN DER MAAREL. 1978. *The Braun-Blanquet approach. Classification of plant communities* (ed. R.H. Whittaker). Junk, The Hague, pp. 287-394.

Recibido: 19. iii. 2002
Aceptado: 15. xii. 2002